Short Sample Test Data IV

M. E. Price, R. Yamada, R. Pighetti

June 26, 1975

In addition to running short sample tests on regular
superconducting wires, the resistance of copper crimps has
been measured. Several solenoids have been built and their
characteristic data relative to short sample data were in-
vestigated.

I.   Short Sample Test Data

In recent months short sample tests have concentrated on
many wires made by two companies: MCA and IGC. Also run were
two unsoldered samples produced by IMI: a 7-strand and an
11-strand sample. A single Supercon 17-strand sample and
another of Supercon 7-strand wire were tested.

I.1 MCA

The MCA wire came in a variety of configurations: 7-strand,
75 x 150 mil; 11-strand, 50 x 150 mil; 13-strand, 75 x 250 mil,
and 17-strand, 50 x 225 mil. The data on MCA wire is shown in
Table I, and their parameters are listed in Table III.

Of the 7-strand wire, MCA had the single best sample, but
there were large variations ($\sim$20%) in the data from sample to
sample.

The single 13-strand MCA sample had an I_c of 5280 at 50 KG

and $\rho=10^{-12}\Omega$. These two types of cable are made from identical 37 mil strands. The current density in the superconductor (J_c) is about 10% lower for the larger wire. However, the 13-strand wire does not have a proportionately larger cross section so there is little difference in the overall current density (I_{eff}).

Only two samples of the MCA 11-strand were tested. There were three months between samples but they varied by only 4%. At $\rho=10^{-12}\Omega cm$ and 50 KG I_c = 2370 amp.

Four MCA 17-strand samples were tested; one turksheaded, two keystoned, and one keystoned and flattened. The turksheaded sample tested slightly better than the two keystoned samples. The difference was about 5% which may be due to compactness of keystoned wire. The keystoned and flattened sample was squeezed when hot to eliminate some of the solder. This sample behaved erratically, with the highest quench current for each field more than 30% greater than that of the lowest. The wire was obviously degraded by this procedure. This was probably due to a poor solder bond and resultant strand movement.

The 11-strand and 17-strand cables are made from the same 25 mil strands. The smaller 11-strand wire has a higher J_c and I_{eff} than the corresponding 17-strand turksheaded wire. Keystoning causes I_{eff} to increase by 20% in the 17-strand wire, but there is no keystoned 11-strand sample to compare this with.

I.2 IGC

All of the IGC wire was 7-strand, 75 x 150 mil. The nine

samples of IGC wire were much more uniform, with variations of

less than 4% over two months. At $\rho = 10^{-12} \Omega$cm and 50 KG, the IGC

wire carries about 3600 amp. The data of IGC and others are

listed in Table II.

I.3 IMI

The 7-strand wire has more NbTi than either the MCA or

IGC seven strands so J_c is very low. The 11-strand has the same

amount of superconductor as 11-strand MCA. The overall dimen-

sions of these wires are smaller so their effective current

densities I_{eff}, are comparable to the other wires.

I.4 Supercon

The 17-strand Supercon wire was unsoldered. Its critical

current at 50 KG was 2300 amps as opposed to a design current

of 2700 amps. The 7-strand sample had been flattened by about

10 mils. I_c and J_c were unaffected and I_{eff} increased.

The short sample test data for the last year are shown

in Fig. 2 for cabled 7- and 11-strand wires.

II. Test Data of Sta-Brite

In a previous report[1] we reported on the superconductivity

of 50-50 and 60-40 solders. We have since tested Sta-Brite

solder (5% Ag and 95%Sn) which is used in the production of many

of the cables tested. The Sta-Brite was not superconducting in liquid helium. At 4.2°K, the resistivity was $2.3 \times 10^{-8} \Omega$ cm or about the same as that of copper. At 7°k $\rho = 2.8 \times 10^{-8} \Omega$ cm, at 12°K $\rho = 4.0 \times 10^{-8} \Omega$ cm, and at 300°k $\rho = 1.9 \times 10^{-6} \Omega$ cm. The resistivity ratio of the copper will be affected very little by Sta-Brite solder since their resistivities are so similar at room temperature and near liquid He temperature.

III. <u>Copper Crimps</u>

A variety of copper crimps designed to be used between magnets were tested for resistance and current-carrying capability. This idea was originated by W. Hanson. Since the crimps are to be used between magnets they will not be subject to high fields.

Without an external field or current through them, these crimp joints show superconductivity due to solder filling. Depending on the sample, the superconductivity disappears at fields ranging up to 700 oersteds either from an external source or a self field. The transition temperature is around 5 to 6°K, depending on that of solder.

Samples were tested at 0 KG, 1 KG, and 5 KG, while immersed in liquid helium. At each field, 3000 amps were passed through the sample and the DC voltage across the sample was measured. The resistances varied from $15 \times 10^{-8} \Omega$ to $.39 \times 10^{-8} \Omega$. Therefore, the power being dissipated at 3000 amp varied from 1.4

watts to .04 watt for DC operation. The best crimp was a
copper U-channel filled with solder and dissipating .04 watt. Two
samples of larger crimps without solder were only slightly
worse, dissipating about .05 watt. Table IV lists the crimps
and pertinent data.

IV.   Solenoid Test

It was felt that the data from the six inch sample used
in the short sample test might not be a valid limit for the
doubler bending magnets. In order to obtain data on an inter-
mediate length of wire, several solenoids were built and their
current carrying data were tested.

The solenoids have a 2" I.D. and are about 3" long. There
are four layers of wire wound so that the wide side of the
wire is parallel to the axis of the mandrel. The number of
turns per layer depends on the width of the wire and so far
varies from 10 to 18. The wire is barber pole wrapped in B-stage
glass tape.

In these solenoids mechanical stability was the primary
concern, and no special efforts were made to insure good
cooling except providing four grooves on the surface of the
mandrel. Also, regular short sample tests were run on pieces
of wire taken from both ends of the solenoid wire.

IV.1. Solenoid Test Value and Short Sample Test Data

All solenoids reached short sample value when there was
no bias field. The first two showed several training quenches,

but the third had no training.

On the first solenoid small G-10 pieces were used to fill
in any empty spaces but these were inadequate. This solenoid
was made from 7-strand Supercon wire. With a forward bias
field applied there was extensive training, but short sample
value was never obtained. The mechanical structure was not
good, causing the extensive training. When a reverse bias
was applied, after a few training quenches the solenoid sample
self-destructed.

In the later solenoids a putty-like epoxy (XD582 manufac-
tured by Cyba-Geigy) was forced into the spaces where the wire
spiralled into the next layer. The putty-epoxy was also placed
around the ends of the wires near the power leads. This worked
much better.

On the second solenoid which showed a slight training, a
wire had moved a little near the end. This one was made from
7-strand IGC wire. Pulling it out, a small amount of epoxy
was placed around the wire and the solenoid was retested.
This time there was no training when we used no bias field.
A forward bias field of 20 and 40 KG was applied and the
solenoid quenched at short sample data value without training.
In the second and third solenoids, for various bias fields,
the quench values ranged from short sample value to 4% above
this. Data of solenoid #2 are shown in Fig. 3, and those of
solenoid #3 in Fig. 4.

IV. 2. Ramp Rate Sensitivity of Solenoid Coil

The solenoid made of IGC wire was checked for ramp rate sensitivity. Typically the solenoids were ramped up to quench at $\sim$20 amp/sec for the previous tests. This rate was increased to $\sim$170 amp/sec without affecting the quench value.

The solenoid was then cycled between 1000 amps and 4200 amps (93% quench value, 97% short sample). The ramp had a 10% flat top and bottom and 40% each for up and down. The cycle was started at 100 sec or 80 amp/sec. This was gradually decreased to 7.5 sec or 1070 amp/sec. The solenoid was allowed to cycle here for some minutes without any problems: no noticeable heating or helium blow off. The cycle was decreased to 5 sec or 1600 amp/sec, at which point the solenoid quenched - not died.

IV.3. Effect of Potting Solenoid Coil With Epoxy

This solenoid was potted completely with epoxy (NMA-hardner; DER 332 resin) and retested. The performance of the solenoid deteriorated after potting.

When no bias field was present, extensive training was required. The quench values after training (40 times) ranged from 2% to 5% below those of the unpotted coil and they are shown in Fig. 3. The actual value depended on the ramp rate.

With a bias field applied, the solenoid had consistent quenches after several training quenches. For different bias fields, the final quench values ranged from 3% to 5% below the

values for the unpotted coil. There was very little variation
with ramp rate.

The potted coil was cycled between 1000 and 4000 amperes.
The cycling was started at a rate of 120 amp/sec and increased
until the solenoid quenched at 540 amp/sec. There was signi-
ficant helium boil off. The upper limit on the cycle was
changed to 3500 amp. This time the rate was increased to 900
amp/sec before the solenoid quenched.

The solenoid was removed from He, allowed to sit warm for
two days, then retested. There was no training; other results
were the same.

A solenoid will be wound with the wide side of the wire
perpendicular to the mandrel. Also different epoxy will be
used for potting.

So far, training appears to be due to mechanical stress
and motion. With good mechanical design, short sample data
can be obtained with solenoid coils. Completely potting with
epoxy caused training and did not allow adequate cooling.
These observations might be useful in building future larger
magnets.

References

1. M. Price, et al "Short Sample Test Data III",
   Fermilab TM-567, March, 1975
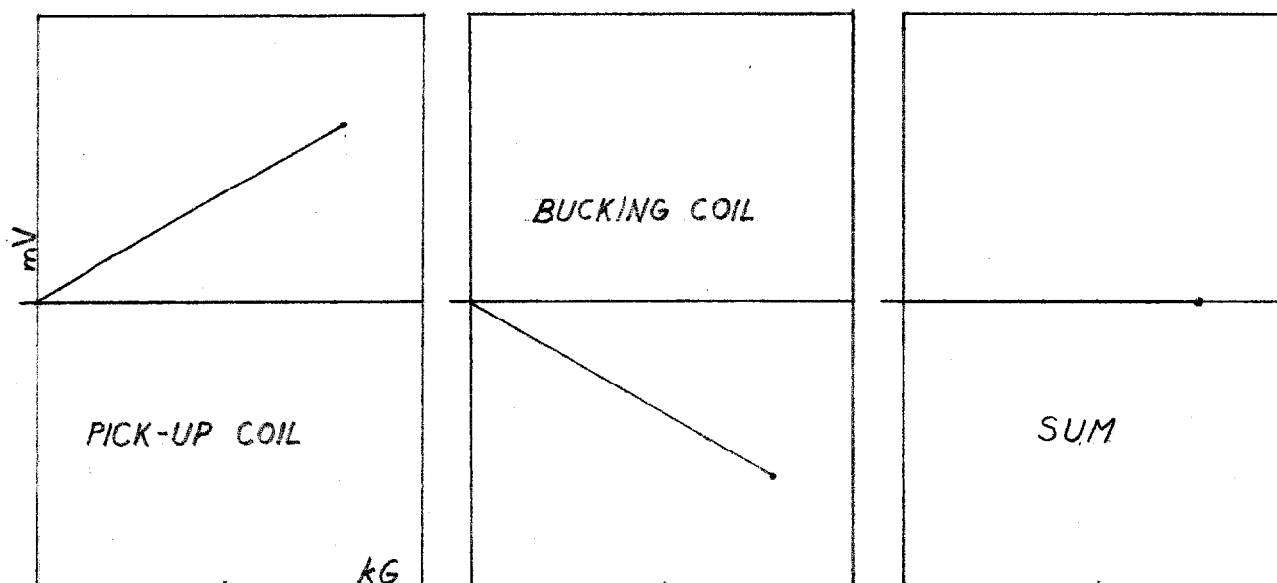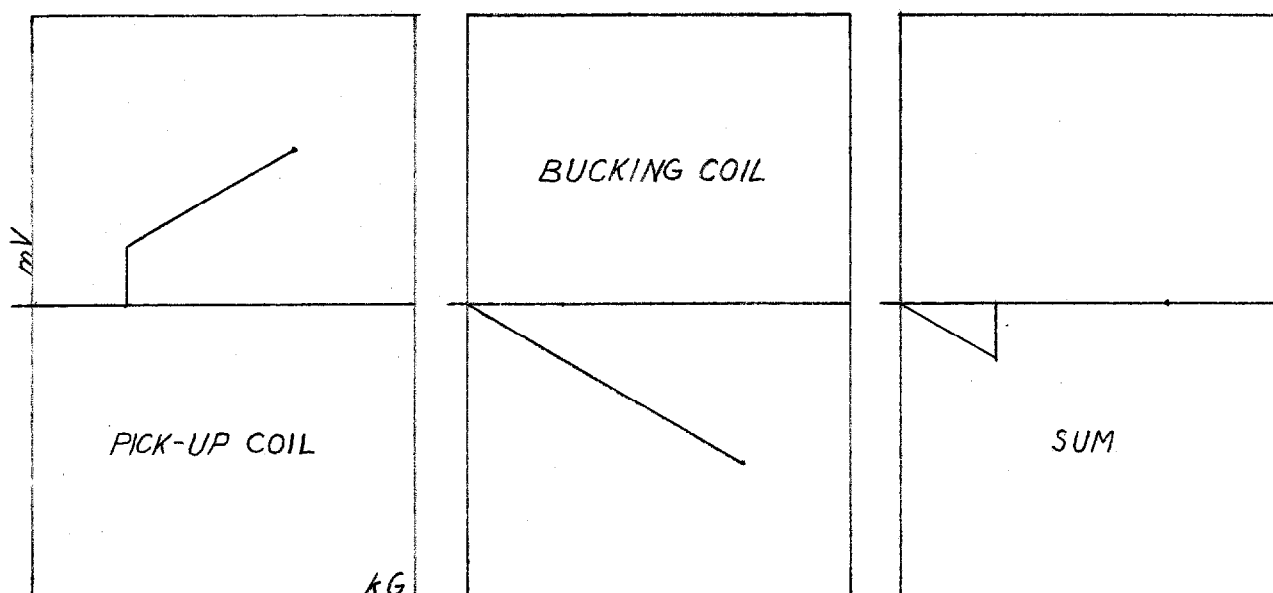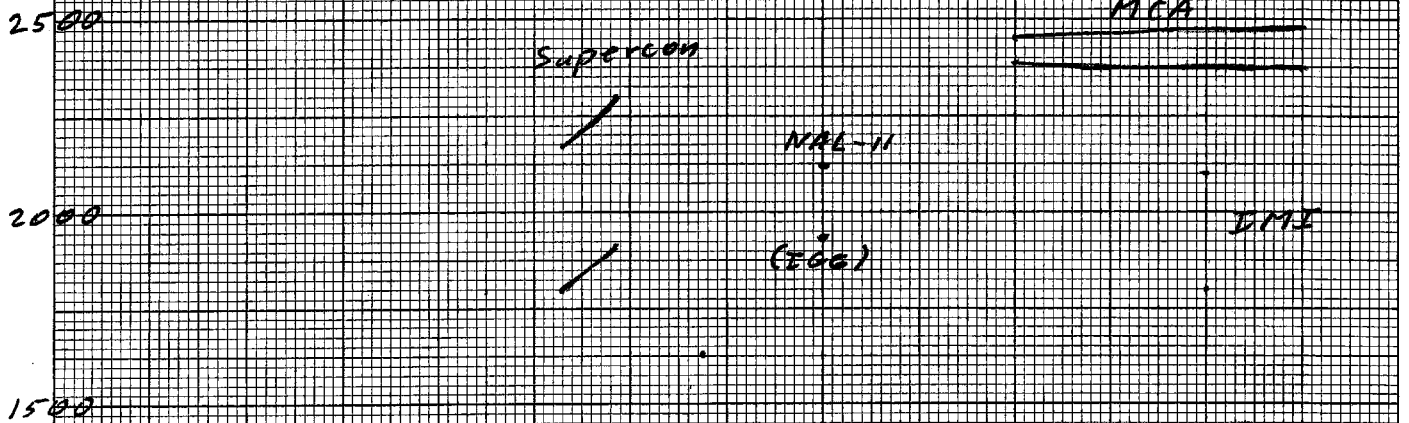
Figure 1a

When no sample is present
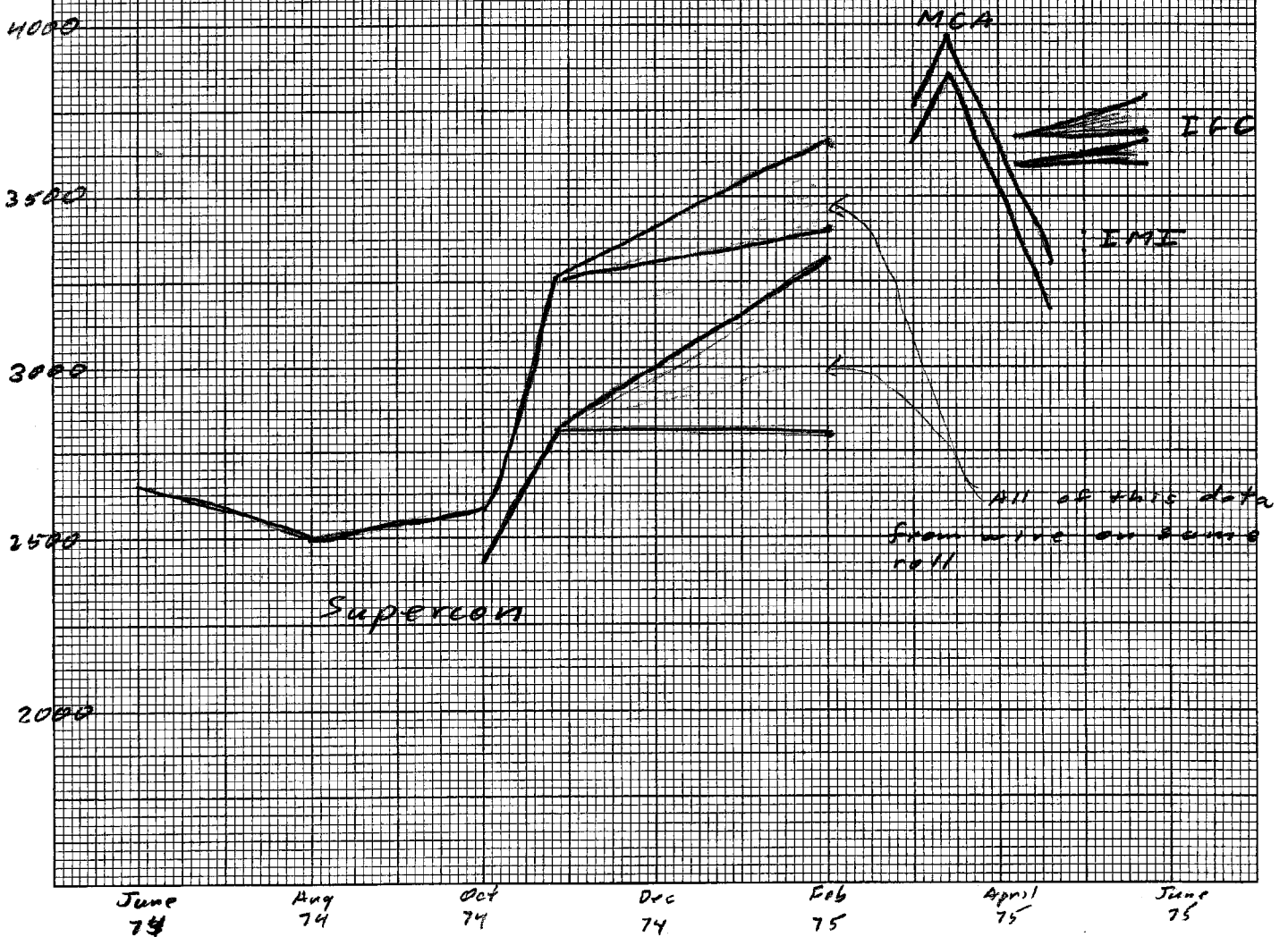

Figure 1b

When sample is present(Type I Superconductor)

7 and 11 strand Wire

TM-587
0428

5/6/75

data at 50 kG

11 strand wire

Supercon

MCA

NAL-11

IMI

(EGG)

2500

2000

1500

7 strand wire

MCA

IGC

IMI

4000

3500

3000

All of this data from wire on same roll

2500

Supercon

2000

| June 74 | Aug 74 | Oct 74 | Dec 74 | Feb 75 | April 75 | June 75 |
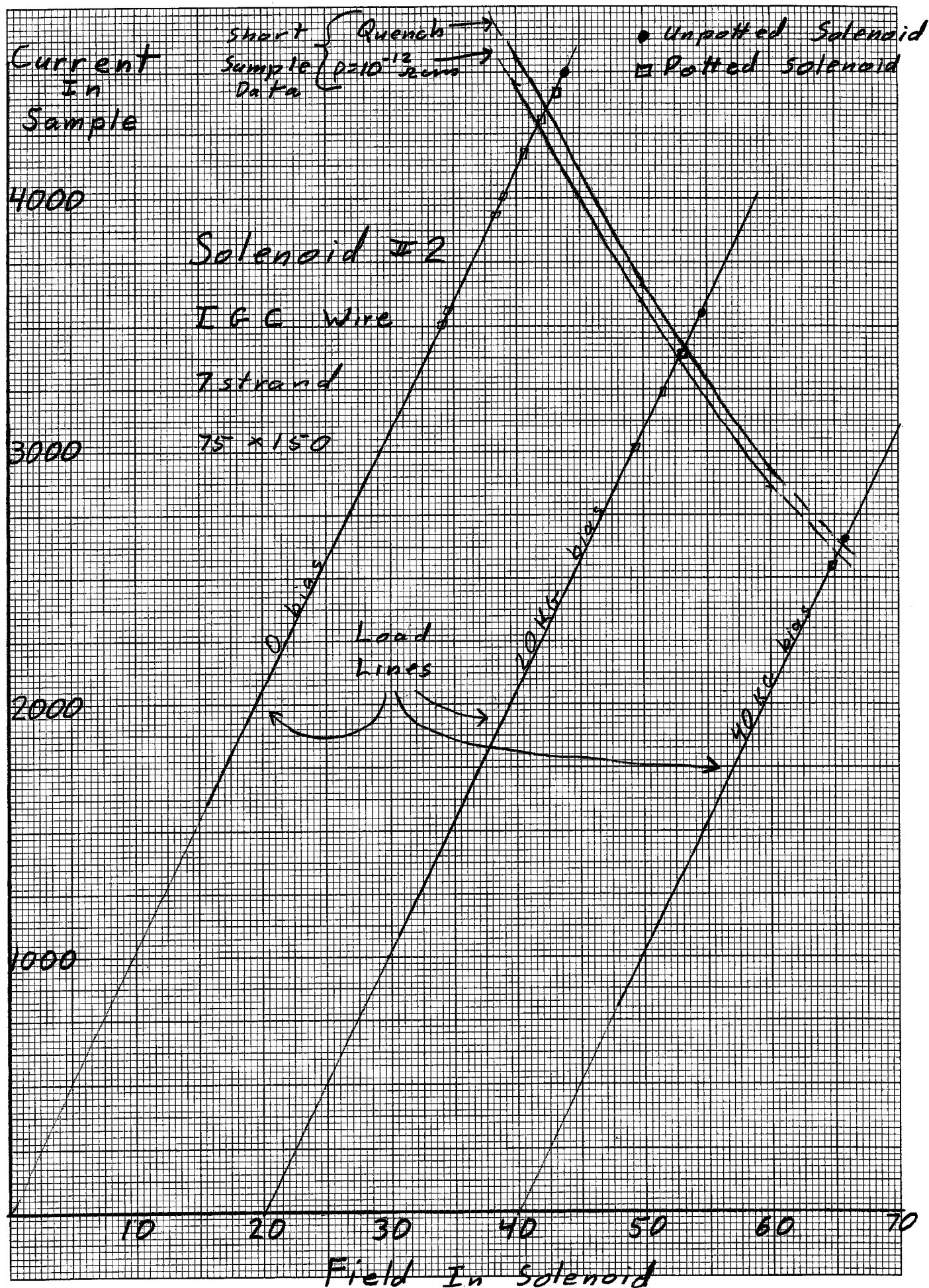
Fig.3
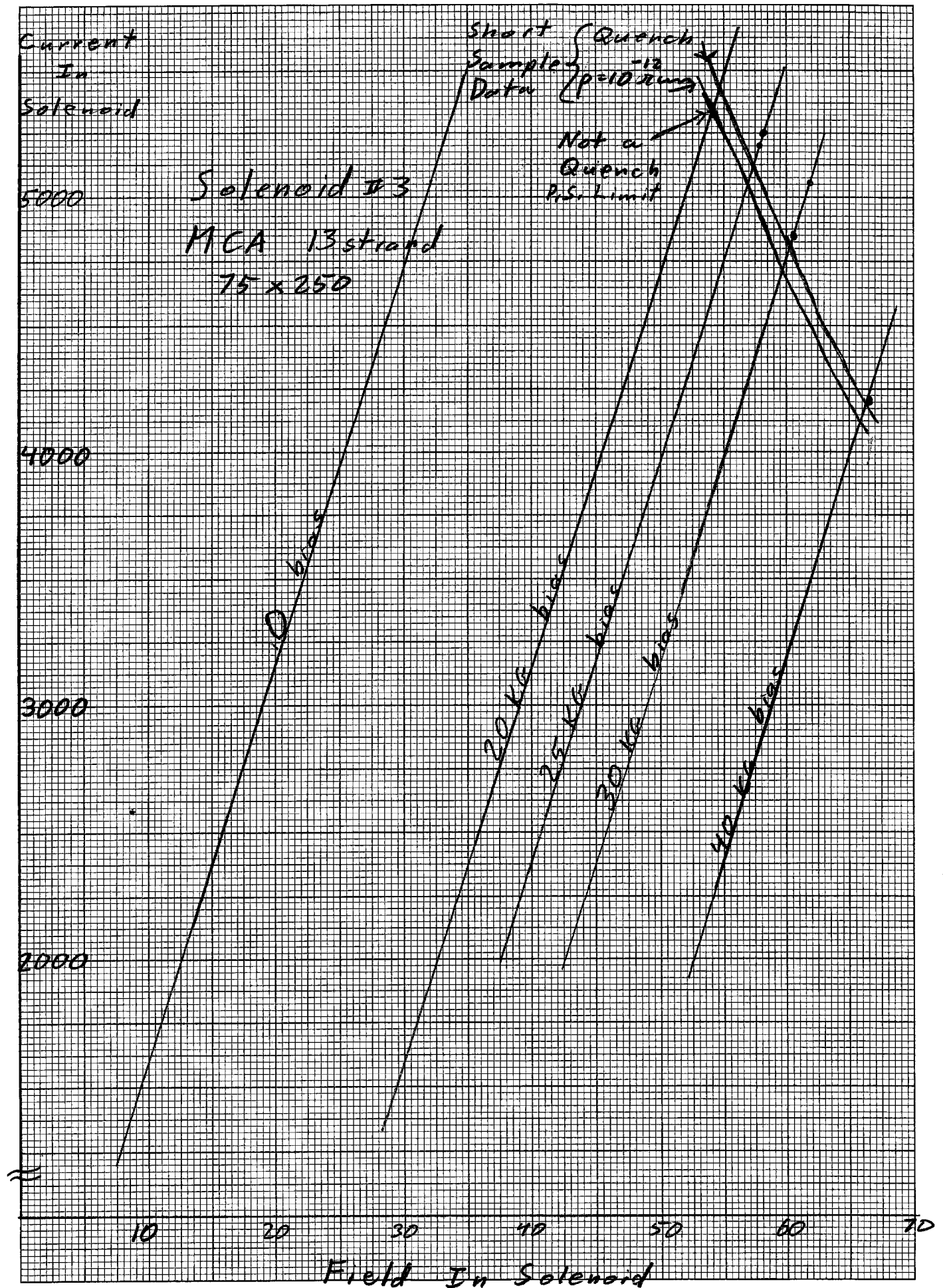
FIG. 4

SAMPLE		40KG	50KG	60KG	ρ At Quench	J_c (KA/cm^2)	I_{eff} (KA/cm^2)
37 mil Wire							
MCA 75x147 (best sample)	Quench	4690	3970	3390	3×10^{-12}	229	56
7-strand Turksheaded							
March 11, 1975	$10^{-12}\Omega cm$	4580	3860	3280		223	54
MCA 76x152 (typical)	Quench	4050	3300	2660	4×10^{-12}	191	44
7-strand Turksheaded							
April 17, 1975, Roll 31	$10^{-12}\Omega cm$	3910	3170	2570		183	43
MCA 76x252	Quench		5820	4770	6×10^{-12}	180	47
13-strand Turksheaded							
April 17, 1975, Roll 32	$10^{-12}\Omega cm$		5280	4370		164	43
25 mil Wire							
MCA 51x151	Quench	3010	2480	2040	3×10^{-12}	199	50
11-strand Turksheaded							
June 4, 1975, Roll 43	$10^{-12}\Omega cm$	2850	2370	1920		191	48
MCA 52x249	Quench	4450	3610	2960	2×10^{-12}	188	43
17-strand Turksheaded							
April 14, 1975, Roll 30	$10^{-12}\Omega cm$	4390	3520	2850		183	42
MCA $\frac{44}{49}$ x 226	Quench	4340	3580	2950	2×10^{-12}	186	53
17-strand Keystoned							
April 16, 1975, Roll 30	$10^{-12}\Omega cm$	4260	3450	2840		179	51
MCA $\frac{41}{44}$ x 233	Quench	2180-4340	2350-3530	2200-2950	7×10^{-12}	122-183	37-55
17-strand Keystoned							
Flattened	$10^{-12}\Omega cm$	3970	3120	2590		162	49
April 24, 1975, Roll 30							

TABLE I

Short Sample Data of MCA Wires
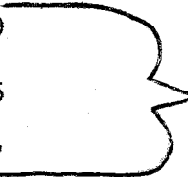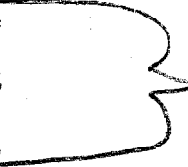
TABLE II

SAMPLE		40KG	50KG	60KG	ρ At Quench	J_c (KA/cm^2)	I_{eff} (KA/cm^2)
IMI (Both samples Turksheaded and unsoldered)							
7-strand 69x141	Quench	3990	3390	2830		173	54
May 7, 1975							
Roll 34	$10^{-12}\Omega\mathrm{cm}$	3970	3340	2760		170	53
11-strand 44.5x136	Quench	2480	2100	1770		169	54
May 7, 1975							
Roll 35	$10^{-12}\Omega\mathrm{cm}$	2140	1810	1440		145	46
IGC (Samples Turksheaded)							
7-strand 75x151	Quench	4490	3670	2920	3×10^{-12}	212	50
April 26, 1975							
Roll 33	$10^{-12}\Omega\mathrm{cm}$	4430	3590	2830		207	49
7-strand 76x152	Quench	4590	3680	2950	2×10^{-12}	212	49
May 22, 1975							
Roll 41	$10^{-12}\Omega\mathrm{cm}$	4570	3670	2850		212	49
SUPERCON							
17-strand 36x196	Quench	2820	2400	2020	3×10^{-12}	139	53
March 25, 1975	$10^{-12}\Omega\mathrm{cm}$	2720	2300	1960		133	51
7-strand $\frac{57}{65}$x150	Quench	4230	3550	2910	5×10^{-12}	143	60
April 9, 1975							
Roll 22	$10^{-12}\Omega\mathrm{cm}$	4000	3300	2780		134	56

	No. of Strands	Strand Diameter (mils)	Filament Diameter (μ)	No. of Filaments	Cu/S.C. Ratio	Area of S.C. (Cm^2)	Filament Pitch (in)	Cable Pitch (in)
MCA 75x147 March 11	7	37	11.7	16100	1.8/1	.01732	.5	2.25
MCA 76x152 April 17, Roll 31	7	37	11.7	16100	1.8/1	.01732	.5	2.25
MCA 76x252 April 17, Roll 32	13	37	11.7	29900	1.8/1	.03216	.5	2
MCA 51x151 June 4, Roll 43	11	25	7.9	25300	1.8/1	.01244	.5	1.75
MCA 52x249 April 14, Roll 30	17	25	7.9	39100	1.8/1	.01923	.5	1.6
MCA $\}^{44}_{49}$ x226 April 16, Roll 30	17	25	7.9	39100	1.8/1	.01923	.5	1.6
MCA $^{41}_{44}\}$ x233 April 24, Roll 30	17	25	7.9	39100	1.8/1	.01923	.5	1.6
IMI 69x141 May 7, Roll 34	7	39.4	13.2	14245	1.6/1	.01963	.47	~1.28
IMI 44.5x136 May 7, Roll 35	11	25	8.4	22385	1.6/1	.01244	1.24	~1.28
IGC 75x151 April 26, Roll 33	7	37	12.3	14700	1.8/1	.01734	.27	2
IGC 76x152 May 22, Roll 41	7	37	12.3	14700	1.8/1	.01734	.27	2
Supercon 36x196 March 25	17	20	6.6	51000	1/1	.01723		1.25
Supercon $^{57}_{65}\}$150 April 8, Roll 22	7	37	29		1/1	.0247		21

TABLE III

Parameters of Superconducting Wires

TABLE IV
TEST DATA OF COPPER CRIMPS

Serial Number	$\sim 300^{\circ}K$ R at 1 amp at 0 KG	$\sim 4.2^{\circ}K$ R at 3000 amp at 5 KG	$\sim 4.2^{\circ}K$ P at 3000 amp at 5 KG	Shape of Crimp
206	$18 \times 10^{-4}\,\Omega$	$8 \times 10^{-8}\,\Omega$	.72 watt	▱
207				⌣
208	14×10^{-4}	15×10^{-8}	1.35	
209	12×10	1.8×10^{-8}	.16	▱
210	12×10^{-4}	$.39 \times 10^{-8}$	.04	⎿⎽
212		2.1×10^{-8}	.19	
214		1.7×10^{-8}	.15	▱
214-S		$.77 \times 10^{-8}$	.07	
215		1.5×10^{-8}	.14	
217		$.53 \times 10^{-8}$	.05	▢
218		$.58 \times 10^{-8}$	.05	
219	9×10^{-4}			
231	18×10^{-4}	3.6×10^{-8}	.32	▨
231-S		3.23×10^{-8}	.29	▩
6" long MCA 7-strand without clamp (for comparison)	11×10^{-4}	$\sim 0 < 10^{-11}\,\Omega$ $\rho \stackrel{\leq}{=} 10^{-14}$		